Ernest Orlando Lawrence Berkeley National Laboratory

Earth Sciences Division Research Summaries 2006-2007

A Perspective from the Division Director

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Research in earth and atmospheric sciences has become increasingly important in light of the energy, climate change, and other environmental issues facing the United States and the world. The development of new energy resources other than fossil hydrocarbons, the safe disposal of nuclear waste and greenhouse gases, and a detailed understanding of the climatic consequences of our energy choices are all critical to meeting energy needs while ensuring environmental safety. The cleanup of underground contamination and the preservation and management of water supplies continue to provide challenges, as they will for generations into the future.

To address the critical energy and environmental issues requires continuing advances in our knowledge of Earth systems and our ability to translate that knowledge into new technologies. The fundamental Earth science research common to energy and environmental issues largely involves the physics, chemistry, and biology of fluids in and on the Earth. To manage Earth fluids requires the ability to understand their properties and behavior at the most fundamental molecular level, as well as prediction, characterization, imaging, and manipulation of those fluids and their behavior in real Earth reservoirs. The broad range of disciplinary expertise, the huge range of spatial and time scales, and the need to integrate theoretical, computational, laboratory and field research, represent both the challenge and the excitement of Earth science research.

The Earth Sciences Division (ESD) of the Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) is committed to addressing the key scientific and technical challenges that are needed to secure our energy future in an environmentally responsibly way. Our staff of over 200 scientists, UC Berkeley faculty, support staff and guests perform world-acclaimed fundamental research in hydrogeology and reservoir engineering, geophysics and geomechanics, geochemistry, microbial ecology, climate systems, and environmental engineering. Building on this scientific foundation, we also perform applied earth science research and technology development to support DOE in a number of its program areas. We currently organize our efforts in the following Division Programs:

- **Fundamental and Exploratory Research**—fundamental research in geochemistry, geophysics, and hydrology to provide a basis for new and improved energy and environmental technologies
- **Climate and Carbon Sciences**—carbon cycling in the terrestrial biosphere and oceans, and global and regional climate modeling, are the cornerstones of a major developing divisional research thrust related to understanding and mitigating the effects of increased greenhouse gas concentrations in the atmosphere
- **Energy Resources**—collaborative projects with industry to develop or improve technologies for the exploration and production of oil, gas, and geothermal reservoirs, and for the development of bioenergy.
- **Environmental Remediation and Water Resources**—innovative technologies for locating, containing, and remediating metals, radionuclides, chlorinated solvents, and energy-related contaminants in soils and groundwaters
- **Geologic Carbon Sequestration**—development and testing of methods for introducing carbon dioxide to subsurface geologic reservoirs, and predicting and monitoring its subsequent migration.
- **Nuclear Waste and Energy**—theoretical, experimental, and simulation studies of the unsaturated zone at Yucca Mountain, Nevada.

These programs draw from each of ESD's disciplinary departments: Climate Science, Ecology, Geochemistry, Geophysics, and Hydrogeology. Short descriptions of these departments are provided as introductory material.

In this document, we present summaries of selected current research projects. While it is not a complete accounting, the projects described here are representative of the nature and breadth of the ESD research effort. We are proud of our scientific accomplishments and we hope that you will find this material useful and exciting. A list of publications for the period from January 2006 to June 2007, along with a listing of our personnel, are also appended. Any comments on our research are appreciated and can be sent to me personally.

Acknowledgments

We gratefully acknowledge the support of our major sponsors in the Department of Energy, which include the Office of Science, the Office of Fossil Energy, the Office of Energy Efficiency and Renewable Energy, and the Office of Civilian Radioactive Waste Management. We also appreciate the support received from other state and federal agencies such as the Bureau of Reclamation, the Department of Defense, the Environmental Protection Agency, NASA, and others. Lastly, we must also acknowledge and thank our industrial collaborators, universities, and other National Laboratories, who provide both financial and in-kind support through various partnership projects, and who bring additional ideas, data, and expertise to ESD.

Earth Sciences Division Operations and Facilities

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OUR ORGANIZATION

Management (and Name) Changes

In November 2007, the Earth Sciences Division (ESD) welcomed its new Director, Don DePaolo. A professor at UC Berkeley in the Earth and Planetary Science Department, Don is also the long-time head of the Center for Isotope Geochemistry, as well as ESD's former Geochemistry Department Manager. Consequently, he was no stranger to ESD and knew what was in store for him. To quote his words at his first Town Hall meeting with the entire ESD staff, "So far it's been fun!" and we hope the fun continues. Ernie Majer, who had stepped in as the Acting Division Director in November 2006, gladly handed over the reigns (and a new management team) to Don.

In early 2006, in keeping with the rotational nature of the Department Head role, Curt Oldenburg was succeeded by Stefan Finsterle for the Hydrogeology Department, and Mark Conrad took over the Geochemistry Department from Don DePaolo. In the summer of 2006, Jim Berryman was hired to assume the Geophysics Department Head role from Ernie Majer. By April 2007, Bill Collins was hired to lead the new Climate Science Department. In addition, the Geologic Carbon Sequestration Program was formed, led by Larry Myer and Curt Oldenburg. Finally, in the fall of 2007, Ernie Majer assumed full Program Head responsibilities for Energy Resources. Also note that since the beginning of 2006, there have been slight changes to the Division Program names, which are reflected in the Organizational Chart (p. ii).

For more information on Berkeley Lab's organization, please visit http://www.lbl.gov.

OUR SAFETY CONSCIOUS WORK ENVIRONMENT

The ESD approach to safety includes Berkeley Lab's Integrated Safety Management model. This model identifies the individual employee as the first person accountable for his or her own health and safety, assisted by a Division Safety Coordinator, who in turn works with a Berkeley Lab Environmental Health and Safety Liaison, to maintain an open line of communication with Berkeley Lab's Environmental Health and Safety Division. Because ESD has a matrixed structure, the employee works with both supervisors and principal investigators to identify, manage, and elevate issues to the ESD Safety Coordinator, Department Head, and Division Director. Additionally, the ESD Safety Committee meets regularly to discuss ESD and Berkeley Lab issues.

In November 2007, Vassiliki "Vivi" Fissekidou was appointed as the new ESD Safety Coordinator and the Chair of the ESD Safety Committee. The ESD Safety Committee also implemented a 3-year-service rotation for its members. The members include representatives from each ESD department, as well as additional members that represent specific work environments (laboratories, field work on land and at sea, computational activities, etc.).

Safety will always be a top priority for ESD. We attribute the success of our safety program to all our staff, which has been very cooperative and pro-active in resolving safety issues, providing suggestions on improvements to safety practices, and implementing changes that result in a safer work environment. For more information about ESD's Health and Safety program, visit http://www-esd.lbl.gov/ESDEHS/index.html

TECHNOLOGY TRANSFER

Over the past two years, ESD has partnered effectively with Berkeley Lab's Technology Transfer Department to license software/codes and secure patents (as appropriate) for ESD-developed technologies. We have also earned accolades!

Licenses—The Division successfully licensed several of its software codes, such as Tough-Fx and Tough-Fx / Hydrate Software and EM2D_INV. These codes and others are available for purchase by contacting Berkeley Lab's Technology Transfer

Department. The Tough Family of Codes and information on purchasing these codes can be found at http://www-esd.lbl.gov/TOUGHPLUS/. ESD is continuing to identify and develop more technologies that can be licensed. To learn more about Earth Sciences and Berkeley Lab's available licensed technology, go to http://www.lbl.gov/Tech-Transfer/

Accolades—In 2007, the *R & D Magazine's* 100 Top Technologies award, also known as the "R&D 100 Awards" went to the *Berkeley Unexploded Ordnance Discriminator*, developed by (among others) ESD's Frank Morrison, Erika Gasperikova, Alex Becker, and J. Torquil Smith. In 2006, the award was given to *The Carbon Explorer*, developed principally by ESD's Jim Bishop.

A DIVERSE WORKFORCE

One of ESD's primary goals is to create a supportive environment to attract, nurture, and retain the most qualified and diverse workforce, including under-represented group members. Along with Berkeley Lab's Workforce Diversity Office and the Center for Science and Engineering Education (CSEE), we continually evaluate and identify the necessary tools to support and enrich our workforce. Erika Gasperikova serves as the Chair of the ESD Diversity Committee and is the Representative of LBNL's Best Practices Diversity Council.

WRITING TRAINING AND DEVELOPMENT

In support of employee development and training, ESD was very fortunate to have in-house experts who have volunteered to share their experience and knowledge regarding writing in a scientific environment. One of these courses, was presented by fellow scientists, Karsten Pruess and Yu-Shu Wu several years ago, with much interest. In 2007, we presented the return of Karsten and Yu-Shu for "Science Writing" and added another course offered by ESD's Technical Writer/Editor, Dan Hawkes on "The Art of Science Writing."

FACILITIES/CENTERS

Center for Computational Seismology

The Center for Computational Seismology (CCS), which focuses on geophysical computing research, maintains a state-of-the-art computing environment in support of various seismological and geophysical research programs, in particular the development of new methods for imaging the subsurface and its processes, and methods for visualizing results. A wide variety of modern software and hardware is developed and maintained to support this high-level research. In addition to the many "in-house"-developed codes (three-dimensional modeling, forward and inverse codes, etc.), we use a wide variety of commercially supported packages, including CogniSeis Focus (interactive 3-D seismic processing), Baker-Atlas SEISLINK (VSP and crosswell imaging), GeoQuest GXII (interactive raytrace modeling for surface and borehole data), Lynx (geologic modeling), Earthvision (Dynamic Graphics) AVS (3-D visualization), and the complete Promax/Landmark processing and modeling software. These packages provide a powerful modeling base upon which we build our specialized codes.

Our facilities support research focused on subsurface imaging, using active and passive sources at scales ranging from meters to whole-Earth dimensions. Research activities include the processing and interpretation of vertical seismic profiles (VSP) for fracture detection and fault delineation, induced seismicity associated with energy resources, seismic reflection imaging, single well and crosshole seismic profiling for 2-D and 3-D imaging, fracture detection between wells, and processing/analysis of micro-earthquake data for imaging of geothermal fields. The hardware facilities include multiple Exabyte tape drives, over 8000 Gbytes of hard drive storage, a 24-inch color Versatec plotter, a 36-inch HP color plotter, and multiple X-terminals and workstations. We have recently upgraded our computer system to the new SUN series 4-CPU server, with10 GByte of memory and 4 Tera bytes of disk. We also recently acquired a "pc cluster" with 256 nodes (2 cpu per node) at 3.6 GHz and 4 Gbyte memory per node. In addition, the CCS facility is linked to the National Energy Research Supercomputing Center at Berkeley Lab, which hosts a variety of supercomputers available for use.

Geosciences Measurement Facility

ESD field work is supported by the Geophysical Measurements Facility (GMF), a DOE-supported facility designed to develop and maintain a variety of geophysical and geoscience instrumentation and measurement equipment. For example, research on piezoelectric sources and borehole sensor arrays, as well as high-frequency seismic recording, has been supported by GMF for over 10 years. GMF is the focal point for an extensive inventory of complex scientific equipment used for Berkeley Lab projects, with responsibility for the maintenance,

upgrading, training, and field operations of this hardware. GMF will allow for management of the full complement of sophisticated field instrumentation and associated support vehicles necessary to test and develop a piezoelectric multisource phased array. GMF maintains a state-of-the-art multidisciplinary field instrumentation facility in support of various environmental, geophysical, and hydrogeological research programs at Berkeley Lab. This facility also assists in development of new instrumentation and field methods for investigating the subsurface and its processes by providing professional in-field technical support for scientific staff and management of the complex and varied field studies required in scientific research programs. The GMF includes electronic and mechanical technicians and shop facilities, field support vehicles, (including wireline and recording trucks), and a three borehole test facility.

Center for Environmental Biotechnology

The core microbiology facility of LBNL is in the Center for Environmental Biotechnology, located in Building 70 and 70A. The seven-laboratory unit occupies a total area of 5,290 ft^2. The laboratories are set up for Class II, Type A/B3 molecular- and microbiology work. Level 1 quality and safety assurance procedures are in place. The following work-specific equipment and instruments are available in the laboratories:

- Lietz Laser Con Focal Microscope with digital imaging.
- 5 SterilGARD II 6-foot vertical laminar-flow, biological safety cabinet (Baker);
- 4 Fermantic 5L Extreomophile bioreactors;
- 2 Fairmentec 3L Extreomophile bioreactors
- 2 Avanti J-25 high performance centrifuge (Beckman);
- DU 640 UV/VIS scanning spectrophotometer (Beckman);
- 4 Ultra-low temperature freezer (Revco);
- 2 Axioskop RLF for DIC, phase contrast, epifluorescence, microphotography (Zeiss);
- Integrated SpeedVac (Savant);
- Electroporator;
- Affymetrix Microarray Systems;
- BioRad MyiQ RT-PCR system
- 2 GeneAmp PCR system 9700 (Applied Biosystems)
- Model 600 PCR Workstation Hood (AirClean)
- QuantityOne Gel Documentation System (BioRad)
- Nanodrop model ND 1000 Spectrophotometer
- Nanodrop model ND 3300 Fluorospectrophotometer
- Model 5415-R refrigerated bench top centrifuge (Epindorf)
- FastPrep 120 Bead mill homogenizer (Bio101)
- Dual 96-well tissue homogenizer (Qiagen)
- 3 Coy double wide anaerobic chambers with incubators;
- GeneAmp PCR system 9600 (Perkin-Elmer);
- Expedite 8909 DNA synthesizer (PerSeptive Biosystems);
- Model 377 ABI Prism automated DNA sequencer (Perkin Elmer);
- CHEF DRII pulsed field electrophoresis equipment (Bio-Rad)
- OmniLog Phenotypic Microarray Systems
- MIDI identification system (Hewlett Packard);
- High sensitivity MSD mainframe for the HP 6890 GC (Hewlett Packard).
- BIOLOG microbial identification system (BIOLOG);
- Environmental shakers with photosynthetic light banks (New Brunswick);
- Columbus Instruments Microrespirometer (H, H_2S, CO_2, CH_4, O_2)
- Alliance HPLC system with a 996 photodiodphotodiode array detector and a 474 scanning fluorescence detector (Waters).
- Dionex 2000 Ion Chromatograph
- Sonicator with microprobe
- 1D Gel electrophoresis set up

Other necessary support equipment and installations are also available, such as autoclave, DI-water, refrigerators, freezers for low temperature storage of temperature sensitive materials, balance, ice-maker, shakers, incubators, magnetic stirrer, hotplates, microcentrifuges, computers, different electrophoresis boxes and power supplies, chemical fume hoods. The core facility has access to the Environmental Measurement Laboratory at LBNL.

For more information concerning the Center for Environmental Biotechnology Core Facility, please contact Terry Hazen, phone: 510-486-6223, e-mail: TCHazen@lbl.gov

Soil and Rock Properties Laboratory

At Berkeley Lab's Soil and Rock Properties Lab, electrical resistivity, ultrasonic wave propagation, and hydraulic conductivity can be measured in a triaxial cell equipped to measure all these parameters simultaneously. Confining and axial stresses are set independently to represent *in situ* states of stress. The cell is designed to handle samples from 3-inch-diameter Shelby tubes, using sample transfer techniques developed from geotechnical practice. The sample is jacketed with a flexible membrane, either latex, viton or teflon, depending on the sample texture and fluid composition. Sample length is determined by considerations of ultrasonic wave attenuation and the extent of stratification of the core. Typically, samples of approximately 5 cm lengths are used, although different lengths can be accommodated. The advantage of making these measurements simultaneously on the same sample is that disturbance from sample transfer between test cells, a particular concern for unconsolidated samples, is avoided. The endcaps of the test cell contain 1 MHz piezo-electric crystals for P- and S-wave transmission and receiving, flow ports, and pressure ports. Porous aluminum plates between the sample and the endcaps provide even flow distribution over the sample cross section. Both faces of the aluminum plates are gold coated.

Electrical resistivity is measured by the four-electrode technique. Electrical current is driven through the outside faces, and voltage drop is measured from the inside faces; a GenRad 1692 RLC Digibridge supplies current and measures voltage drops at five test frequencies varying from 100 Hz to 100 kHz. P-wave and S-wave propagation (velocity and attenuation) is measured by the pulse-transmission technique.

Voltage pulses are generated by Cober Model 605P High Power Pulse Generator (Cober Electronics, Stamford, Connecticut), and data are acquired via a 40 MHz Gagescope data acquisition board (Gage Applied Sciences Inc., Montreal, Quebec) installed in a PC. Hydraulic conductivity is measured either by the constant head method for more permeable samples, or by the falling head method for tighter samples. Differential pressure across the column is measured with variable reluctance transducers (Validyne, Northridge, CA). When possible, site water is used for the hydraulic conductivity measurements to avoid dispersion of clays. Otherwise, test water is generated based upon a chemical analysis of the site water. In addition to the above facilities, a high-resolution x-ray facility (linear x-ray and CAT scan) and an NMR imaging facility enables detailed core studies and simultaneous flow and transport studies. Further capabilities are provided by linking these studies with ultra-high-resolution tomographic work at Berkeley Lab's Advanced Light Source.

For more information on CCS, GMF, or the Rock Lab, please contact Ernest L. Majer, phone: 510-486-6709, elmajer@lbl.gov

Center for Isotope Geochemistry

The Center for Isotope Geochemistry (CIG), Lawrence Berkeley National Laboratory, and Department of Geology and Geophysics, University of California, Berkeley, is directed by Prof. Donald J. DePaolo. The Center includes six analytical facilities: stable isotope and noble gas isotope laboratories; a soil carbon laboratory; an analytical chemistry laboratory; the Inductively Coupled Plasma Multi-Collector Magnetic Sector mass spectrometry laboratory, and a thermal-ionization mass spectrometry laboratory located on the UC Berkeley campus. We also have an affiliation with the cosmogenic isotope laboratory in UC Berkeley's Space Sciences Laboratory. These facilities provide state-of-the-art characterization of all types of earth materials for research throughout the department and elsewhere in ESD. The instrumentation and laboratories are an integral part of the Center's focus on new ways to use isotopic ratio methods to study fundamental earth processes and environmental and energy problems of national interest.

Summary of Research Areas and Programmatic Applicability

The research we pursue is ultimately guided not only by the needs of advancing basic energy science (BES), but by applicability to other basic and applied programs within the DOE mission—nuclear waste management (NW), environmental remediation science (ERSP), fossil and geothermal energy resources (FE, GE), climate change and carbon management (CCC), and security.

1. Basic geochemistry (BES)

- Dissolution, precipitation, ion exchange and transport in natural systems
- Isotopic probes of micro- and nanoscale material properties
- Geochronology
- Isotopic variations in nature due to chemical and nuclear processes
- Volcanic processes and volcano monitoring
- Reactive transport: conceptual and numerical models, isotopic effects

2. Groundwater processes

- Field-scale characterization of groundwater systems—flow velocities, effective permeabilities, infiltration rates (ERSP, NW)
- Mineral-fluid reaction rates in fluid-rock systems (ERSP, NW, FE, GE)
- Isotopic monitoring of subsurface remediation (ERSP)
- Isotopic diagnostics for subsurface chemical processes (ERSP, NW, FE, GE)
- Isotopic diagnostics and phase partitioning tracers related to geologic sequestration of carbon (FE, CCC)

3. Hydrothermal systems

- Reservoir characteristics, water and heat sources (GE, NW)
- Relations between volcanism and geothermal potential, volcanic hazards (GE)

4. Sedimentary basin hydrology

- Characterizing geological structure and reservoir properties (FE, ERSP)
- Tracing fluid flow (FE, CCC)
- Sourcing hydrocarbons (FE)

5. Isotopic climate records (GCC, NW)

For more information concerning the Center for Isotope Geochemistry, please contact: B. Mack Kennedy, Center for Isotope Geochemistry, phone: 510-486-6451, e-mail: bmkennedy@lbl.gov